



Guide to Making and Using Biochar for Gardens in Southern Arizona

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What is Biochar?

Biochar is actually just **charcoal** or black carbon, made from the incomplete combustion of **wood** or other **biomass** products. With growing interests in “green” and “carbon-negative” materials, biochar commonly refers to charcoal made from organic wastes such as tree trimmings, scrap wood, and plant material left from agricultural harvests. Like a campfire, wood biomass will burn without any other external fuels or energy. Since burning wood does not add **fossil carbon** to the atmosphere, burning wood or making biochar is a carbon-negative process.

The chunks of charred wood left over from a campfire is a form of biochar. In handling those pieces of campfire biochar, it is easy to note that it is lighter than the wood it came from. In the fire, the most flammable parts of the wood burn away first leaving pores, or airspaces in the charred remains (Figure 1). This porous sponge-like property of biochar makes it useful for many things such as the production of activated carbon filters used to purify water. Industrial production of biochar employs **pyrolysis**; a means of combustion without much air or oxygen and is more efficient in that it produces little **ash**. However, for most uses, including gardening, biochar can be made at home in a purchased or homemade burner as explained further in this publication.

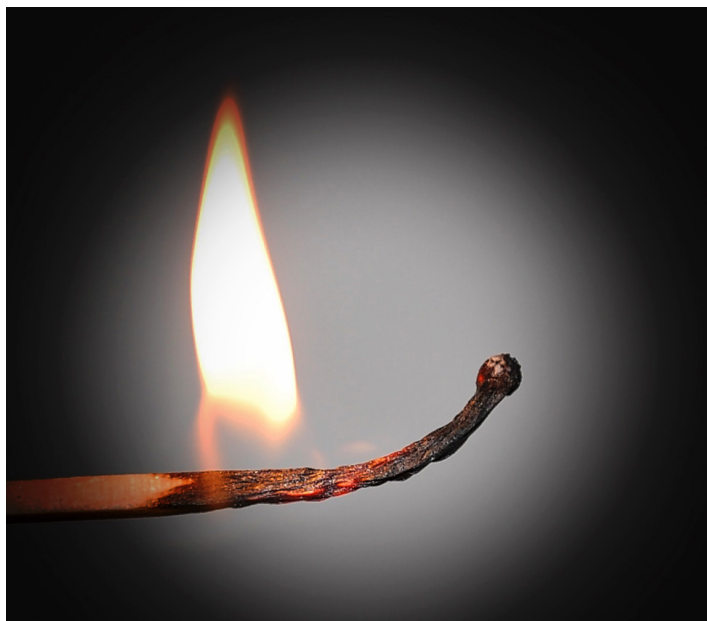


Figure 1. The black portion of the match is charcoal, a light, porous material, made mostly of carbon and other elements. Photo: J. Artiola

Traditional Biochar Uses

Prior to the discovery of oil, natural gas, and coal as energy sources, wood and charcoal were the only means to heat, cook, blacksmith, distill, and power early steam engines. Charcoal production became an important industry since it is lighter and easier to transport than wood. Converting wood to charcoal means it is ~50-75% lighter to carry and yet keeps ~50-60% of the energy as a fuel. Unfortunately, this has been and still is one of the causes of deforestation in many regions of the world that lack access to fossil fuels to meet basic household energy needs.

Biochar is actually an ancient technology for improving soil fertility for agriculture dating back as far as 8,000 years ago in South America. The ancient Amazonian civilizations

used biochar to transform the poor quality red soil into a rich black fertile soil. According to John Roach in National Geographic News (NGN 2008), these dark soils “are hundreds to thousands of years old, yet to this day they retain their nutrients and carbons, which are held mainly by the charcoal.” Similar uses of biochar by earlier civilizations are also found in Peru, Ecuador, West Africa, and Australia.

Traditional techniques for the addition of charcoal (and ash) to soils was probably done with controlled burning of crop residues and/or local vegetation. Additionally, production methods include pit or mounds that are set on fire and then covered with soil to allow for slow smoldering (Figure 2). Even wood ash is particularly useful in reducing soil acidity and adding depleted nutrients such as calcium, potassium, and magnesium to mineral-poor soils.

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Figure 2 Traditional Biochar Production. Burning piles of biomass and covering it with soil will allow it to burn slowly with limited air. Source: <https://www.biochar-journal.org/en/ct/59-Biochar-in-the-time-of-cholera>

Biochar Rediscovered

Improving the condition of soils for agriculture has been the main use of biochar worldwide. New uses such as biofuels, carbon storage, and removing contaminants from water, soil and air are also well known. One author offers 55 uses for biochar (Schmit 2012). Four main factors have renewed interest in the production and use of biochar for agriculture.

First: Biochar is a great way to turn organic waste into something useful and long-lasting. Sources for biochar include any type of plant or animal waste including: trees, shrubs, and grasses; and agricultural residues such as corn stalks, rice hulls, manure, and sewage.

Second: Unlike fossil fuels, the production of biochar does not generate additional carbon dioxide (CO_2) gas emissions that are primarily responsible for global warming. Therefore, making biochar is carbon-negative process.

IMPORTANT PROPERTIES OF BIOCHAR IN AGRICULTURE

- * Creates a use for waste organic material
- * Carbon-negative: it does not generate additional CO_2 emissions
- * Carbon sequestration: provides long-term carbon storage
- * Improves soil fertility in several ways

Third: Carbon sequestration is another application of biochar. As plants grow, they remove CO_2 from the atmosphere; convert the carbon (C) from the CO_2 into roots, stems and leaves while releasing oxygen (O_2) that we breathe. If plant and organic wastes are allowed to decompose, they return most of the CO_2 to the atmosphere (up to 90% within a few years). Biochar is a very stable form of organic carbon lasting hundreds to thousands of years in the soil (Figure 3). Therefore, biochar production helps lower the CO_2 concentration in the atmosphere by not decomposing and storing the carbon long-term. This is a form of carbon sequestration. Some estimates suggest that half of the carbon from the CO_2 that plants remove from the atmosphere can be stored as biochar in soils (Lehmann et al., 2006).

Fourth: Biochar has several agricultural benefits (IBI 2017). Biochar is a sought-after soil additive that increases macronutrients in depleted soils commonly found in hot and wet climates, reduces soil acidity, improves soil texture, and increases the water holding capacity. In addition, recent studies have shown that biochar can reduce nutrient losses and reduce migration of agricultural chemicals such as pesticides and herbicides.

Will Biochar Benefit Alkaline Soils? The use of biochar as a soil additive goes back thousands of years in tropical areas where soils are usually acidic with very low organic matter content and depleted of macronutrients such as calcium and potassium. In contrast, soils in arid and semiarid climates of the Southwest have large supplies of these nutrients and are alkaline (pH greater than 7.5), but are still lacking in organic matter (Artiola & Walworth 2009). Biochar can be beneficial to any type of soil. The addition of biochar to our desert soils will quickly raise the soil organic matter content, increase water holding capacity and improve soil structure. Desert soils do offer special challenges as some research has shown that biochar may also temporarily raise the soil pH and salinity.

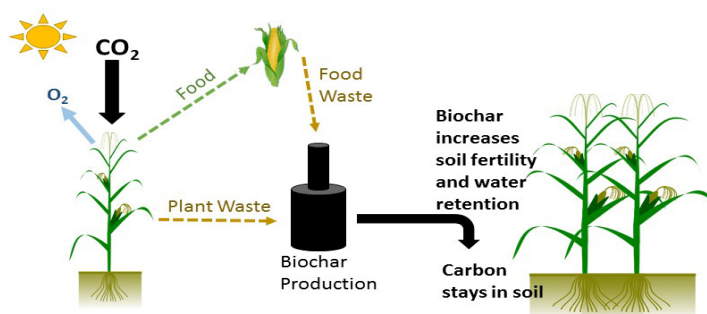


Figure 3. Biochar can help reduce the CO_2 levels in the atmosphere when applied to soil. Carbon from CO_2 is sequestered by plants and ends up as biochar. Image: L. Wardell



Figure 4. Compost piles and green waste (insert) in Tucson. Photos: J. Artiola



Figure 5. Native grasses growing in biochar amended soil after one month of drought. Source: J. Artiola

Compost vs Biochar for the Garden

Driving the effort to develop uses for green wastes, composting has become a common practice. According to the EPA, 34.5 million tons of yard waste was generated in 2014 in the US. Over 60% of yard waste went to composting, with 7.6% burned for energy and just under one-third (10,790,000 tons) ending up in a landfill. Both compost and biochar have their benefits and it is ideal to mix them for a home garden. Although compost is a form of carbon that decomposes much faster in soils than biochar carbon, compost is more readily available. Gardeners can mix biochar with compost to have quick and long-lasting benefits of raising soil organic matter content.

Presently, tens of thousands of tons of yard waste are landfilled in Arizona. However, programs from the City of Phoenix (CoP 2017) and the Tucson-based University of Arizona student organization Compost Cats (CC 2017) along with others are increasingly using urban green wastes (together with food scraps and manure) to produce and sell

compost. Like biochar, compost produced from yard waste in Arizona (Figure 4) can have lots of salts, which can be removed by leaching before the compost can be safely used in nursery potting mixes. Arizona homeowners interested in producing compost in their backyards should refer to the UA Cooperative Extension Publication #AZ1632 for additional information.

Arizona Biochar: Pine Forest and Mesquite Yard Wastes

Arizona has an unending supply of pine forest and mesquite woody wastes. The cooler, higher altitudes produce pine trees where the forestry and wood industry generate a lot of pine waste biomass. In the lower altitudes where it is hot and dry, mesquite trees flourish. Mesquite is an invasive species in rangelands worldwide that is disliked for its ability to tap into precious groundwater resources and for the way it discourages the growth of native grasses. Ranchers and land managers in Arizona spend millions of dollars each year trying to control mesquite. Mesquite is a popular landscape tree in the desert

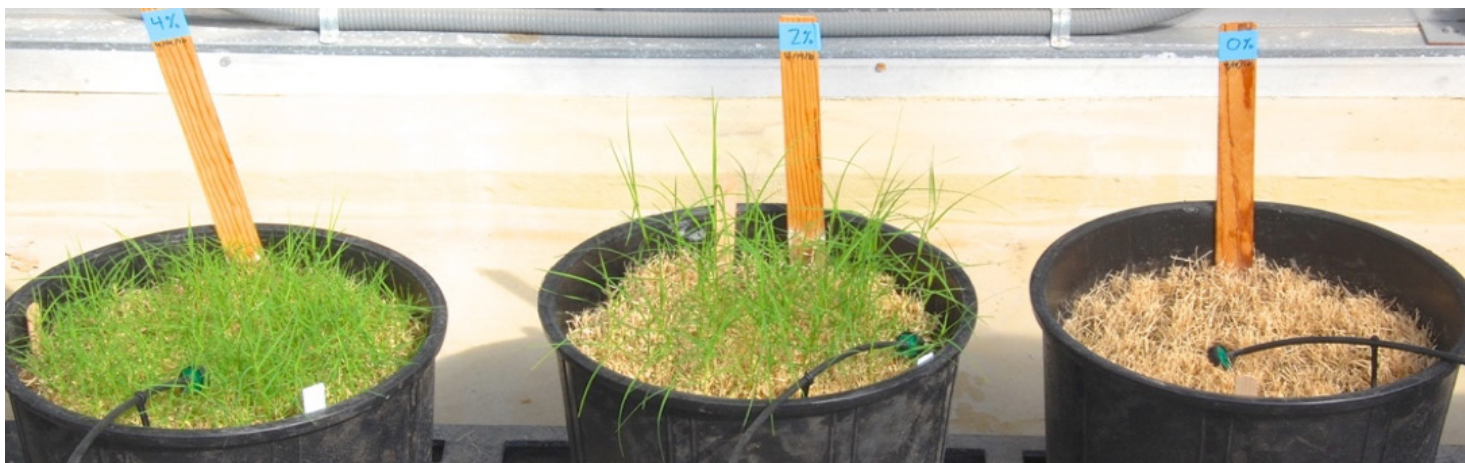


Figure 6. Bermuda grass growing in biochar amended soil after 28 days of drought. The left pot contains 4% biochar (by weight) in the soil and had nearly 100% recovery. The center pot contains 2% biochar and had a recovery of 40-60%. The right pot with 0% biochar had 0% recovery as evidenced by the brown color. Source: Artiola et al., (2012)

cities so ample yard waste is also generated there. This is why researchers at the University of Arizona have focused much of their biochar research on these two sources of wood biomass.

Biochar can help protect turf grass from drought conditions. Research at the University of Arizona has shown that biochar produced from pine forest waste, when applied to soil, increased plant growth and helped protect several native grass species from drought (Figure 5). In a drought experiment (Figure 6), biochar significantly increased the survival rate of Bermuda grass. After one month of drought (no water) the Bermuda grass without any biochar did not recover at all and remained brown. Adding 2% biochar by weight to the soil increased the survival to 40-60%. With 4% biochar, nearly 100% of the Bermuda grass recovered. This is due to biochar increasing the water holding capacity of soils.

In the same study, Romaine lettuce grew better with biochar in the soil. Adding up to 4% biochar (by weight) to a loamy sand soil from Red Rock, Arizona, doubled lettuce yields. The romaine lettuce plants grown without biochar weighed an average of 50 g (1.8 oz). Lettuce grown in soil with 4% by weight biochar were about twice the size, weighing on average 110 g (0.22 lbs) (Figure 7). In other experiments, biochar also helped reduce the fertilizer losses below the root zone and increased plant yields (Artiola et al., 2012).

Lessons Learned: In the very beginning of the above studies the biochar had adverse effects on Romaine lettuce and Bermudagrass. In a saline soil environment such as a desert, plants will generally contain higher levels of salt. These salts will concentrate further when these plants are converted to biochar. When added to the soil, the salts will then wash out of the biochar causing sudden changes in the salt levels of the soil. Our observations showed that these changes affected seed germination, and seedling and plant growth (data not shown). However, after watering the plants several times, the

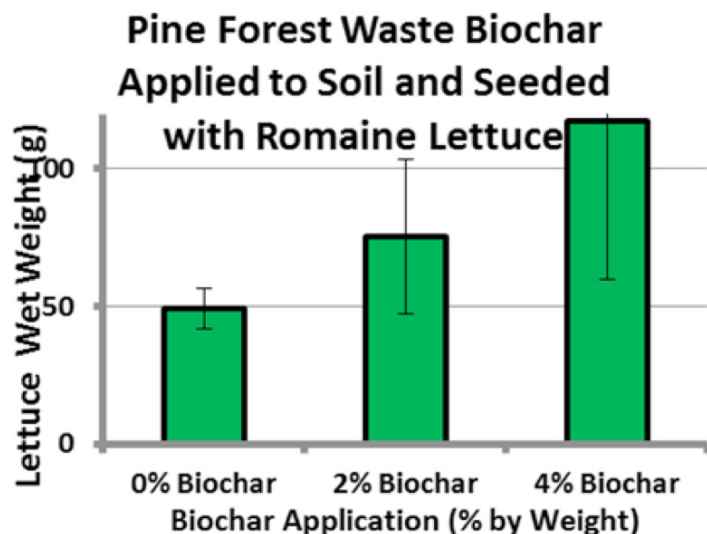


Figure 7. Adding biochar to soil increased the growth of lettuce. Source: Artiola et al., (2012)

soil pH and salinity conditions returned to normal levels. This suggests that biochar has only a temporary effect on the soil salinity of desert soils common in Arizona. See next sections for tips on how to avoid this.

Additional Research: Biochar has some similar properties to activated carbon, found in many pitcher, faucet, and refrigerator filters for drinking water. Activated carbon removes many organic and some metal contaminants from water; so, what about mesquite biochar? In a study at the University of Arizona, biochar made from mesquite yard waste was tested to see how well it would remove common organic contaminants including benzene (common in gasoline), trichloroethylene (TCE) (solvent degreaser), and atrazine (common herbicide). The biochar effectively removed the contaminants. For example, one kilogram (2.2 lbs) mesquite biochar retained more than 15 grams (1 / 2 oz) of benzene and the same amount of biochar retained about one gram of TCE after 3 days of contact time with water tainted with these solvents.

The weed killer Atrazine, one of the most widely used herbicides, was also removed from water by mesquite biochar—over half of the atrazine was removed from the water over a 24-hour period. Therefore, biochar has excellent potential for filtering contaminants from urban, agricultural, and even industrial wastewaters. However, more research and demonstration projects are needed to figure out safe and effective ways to trap these and other chemicals from wastewaters and protect our precious water resources.

How to Make Biochar for Home Use

1. Selecting a Burner/Stove to Make Biochar

Many websites advise digging a trench or a pit to burn your green wastes into biochar but this may be against some urban fire codes or pose a fire risk when the weather is dry. If shopping for a biochar stove, keep in mind that they may also be referred to as wood or biomass gasifiers. The term gasifier describes a stove that will regulate the air during wood burning. Without much air, the most flammable parts of the wood will vaporize as the wood heats up once the fire starts. It is this vapor, or gas, that burns the hottest and makes for a smokeless wood stove (that can make biochar too).

Home Fire Pit/Chiminea or BBQ/Smoker This is the least efficient method. But if you're curious, it is a simple way to start. The black charred wood remaining from a campfire or from cooking with wood in a BBQ grill is biochar. To maximize the amount of biochar and minimize the amount of ash, use a uniform size of wood chunks (wood from a chipper works well) and start a fire. Carefully watch your wood fire and when the yellow flames are about out, it is time to stop the fire by using a lid and suffocating the fire or by quenching it with water.

Cone Stove The simplest biochar stove is a cone or sometimes called a Japanese kiln (Figure 8). This allows air to reach only

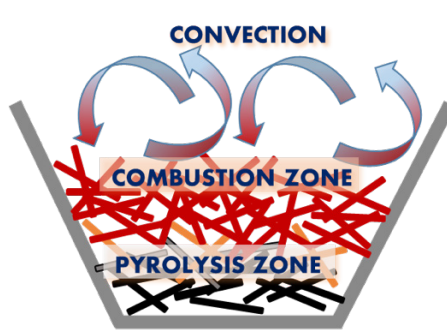


Figure 8. Japanese kiln (left). Source: www.ithaka-journal.net/86. Biochar is produced in the pyrolysis zone where less air is available (center). Source: Image by L. Wardell. Cone with coals -- wood layer is added when the top layer begins to coat with ash (right). Source: www.ithaka-journal.net/86

the top layer, forming biochar below in the bottom called the “pyrolysis zone”. When the top layer begins to coat with ash it is time to add another layer of wood or stop the fire by suffocating it with a lid or dowsing it with water.

Gasifier Stove There are several stoves on the market that homeowners can buy (or build) to cook with and make biochar (Figure 9). These work because the low oxygen conditions needed to make biochar can be created inside an open container by controlling the air that enters from the bottom part where heat produces gases. More air can be forced near the top of the flames to increase combustion efficiency and eliminate smoke.

CAUTION: The top flames are much hotter than the coals and may reach temperatures well above 1,300°F (700°C). Note that there are many variations to the design shown in Figure 9 with either active or passive forced air entry.

The steps for the production of high quality biochar using yard waste (wood branches) includes a small wood chipper and a biochar stove (Figure 10). It is important to stir the woodchips inside the stove during the combustion process or carefully

burn in layers. Using gasifier stoves with forced air reduces the amount of smoke and ash. As soon as the flames die out, move the smoldering coals into a metal can or old pot and seal tightly with a lid. This will prevent air entry and stop the wood from burning further. Then the biochar sits outdoors to cool for several hours. Water can also be used to quench the fire. A batch of mesquite biochar is in the far-right image (Figure 10), using a quarter coin for scale.

2. Choosing Which Yard Waste to Use

Almost any dry organic “green” waste is suitable for making biochar. Homeowners in Arizona with large backyards often have a readily available source of green waste from landscape trees such as Mesquite, Palo Verde, and Mulberry that would make good biochars.

Yard Waste Preparation If you want to produce biochar of consistent size, ready to use in your garden, then the size of the yard waste should also be consistent. Wood chippers produce consistent size wastes that can easily be packed into various types of stoves for the production of biochar. Not

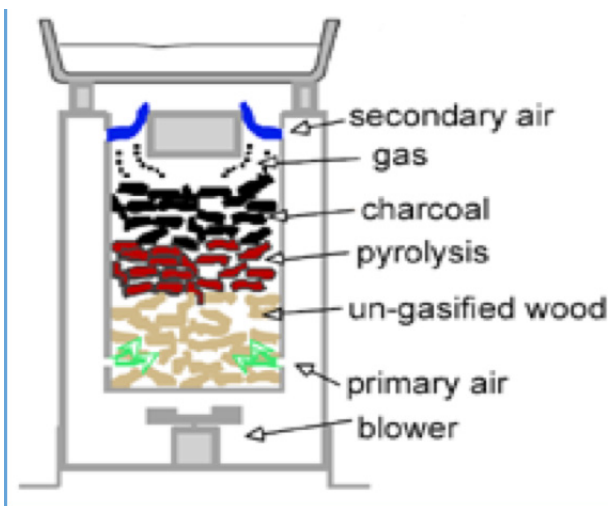


Figure 9. Basics of a Top-Lit Updraft Gasifier stove good for cooking and/or making biochar (left). Source: www.biochar-international.org. One of many types and sizes of camp stoves (center, no endorsement implied). Photo: L. Wardell. Instructions to make one are easily found online. Sizes range from coffee cans (right) to 55-gallon drums. Source: https://energypedia.info/wiki/File:Micro_Gasification_2.0_Cooking_with_gas_from_dry_biomass.pdf



Figure 10. Mesquite Yard Waste (left), Wood Chipper (center-left), Woodgas Gasifier Stove© (center-right, no endorsement implied), Biochar (right). Photos: J. Artiola

CAUTION:

Avoid making biochar from mixed wastes or wastes residues from plants used in hedges such as oleander because this and other plants contain chemicals that protect the plant. If these toxins are not completely burned off, they could adversely affect other plants (Figure 11)



Figure 11. Oleander Hedge. Photo: J. Artiola

all methods for the production of biochar require the use of wood chippers. However, if you end up with large chunks of biochar, they should be crushed before adding to soil. See the cautions in this publication for handling biochar.

3. Biochar Preparation and Soil Application

Does Size Matter? There are no clear recommendations for what biochar size is best to apply to soils. This is because biochar is usually an uneven mixture of carbon-rich particles/chunks that can range in size from dust (< 1 millimeter or < 0.04 inches) to several centimeters. Studies have shown that small biochar particles fill with water faster, retain nutrients, and sorb pesticides better than larger size particles. Under normal field conditions, water, nutrients and other chemicals, will not penetrate deep into large biochar particles because small spaces located deep in the biochar stay filled with air. If biochar is produced using large size wood logs or branches more than 5 cm in diameter (2 inches or more), then it may be desirable to break larger char pieces to an average size no more than a half centimeter (3/8 inch).

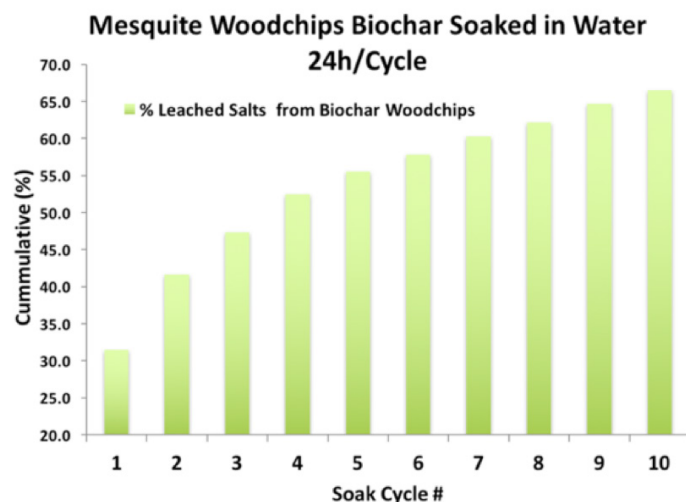


Figure 12. Soaking biochar in water can remove much of the salt. Soaking the biochar once (for 24 hours) removed ~30% of the salt. Repeating the soaks 10 times removed up to 65% of the total amount of salt. Source: J. Artiola

CAUTION: As with most dry soil and dust size particles, breathing biochar dust can be hazardous. Research on soot exposure by chimney sweeps found a range of additional health concerns (Soot, 2017). Cutting or chipping the wood beforehand is preferable over crushing the biochar to avoid making extra biochar dust. But woodchip fires must be stirred often for even combustion. In dry climates, it is also important that biochar is mixed in with the soil or compost and not placed on the garden surface where it can be exposed to wind. Store biochar in sealed containers or bags. If crushing dry biochar, wear a dust mask. Wetting the biochar before using or crushing will help contain the dust. Always handle biochar outdoors.

Removing Salts Leaching salts from biochar (or even compost) is more complicated than simply rinsing it off. Laboratory experiments were conducted and found that rinsing the biochar removed very little of the salt. Soaking the biochar repeatedly using fresh water each time is the best way to wash the salt out. Soaking the biochar once for 24 hours removed about 30% of the salt (Figure 12). Repeating the soakings ten times removed over 65% of the salt. Removing salt will be less effective with larger particles. The exact amount of water and soaking times were tightly controlled in the laboratory; so, doing this ten times is not necessary. At home, letting the biochar sit (submerged) in water overnight or longer should remove a lot of the salt in two or three soaks. Soaking and drying the biochar several times also helps lower the pH of the biochar, which is usually very alkaline (pH above 9). However, salt content of your yard waste will vary with factors such as soil salinity and plant species.

Mixing Biochar with Compost Biochar lacks nutrients like nitrogen and phosphorous so mixing it with compost or manure is a helpful option. Biochar has the ability to sorb these nutrients and keep them in the soil longer and is better than using compost alone. Mixing up to 1 part compost with 1 part biochar is effective at increasing the time nutrients stay in the soil, but most gardeners start with ratios closer to 10 parts of compost to 1 part biochar to be sure that plants tolerate it well. Before adding this mixture to soils, or using it in a potting mix, it should be aged for several weeks under moist conditions to allow for the exchange of nutrients between the two materials. This will also help microorganisms, worms, etc. found in compost to adjust to the biochar. This step also helps beneficial fungi that grow on plant roots to develop quickly once the biochar-compost mix is applied to soil (Charging a, b 2017). Increasing the nutrients in biochar in this way is called “charging”.

4. How much Biochar?

Published studies do not agree on a specific amount of biochar that must be added to soil for optimum benefits. Application rates vary from 1 metric tonnes/hectare (Mt/ha) (~ ½ tons/acre) to well over 100 Mt/ha (446 tons/acre).

There are several reasons for this, here are just a few of them:

The quality of biochar will depend on things like the source of wood used, the temperature it was burned, the size of biochar pieces, and if it was soaked in water or had any other special treatment.

Biochar research projects around the world used very different soils, from nutrient poor tropical soils to sandy desert soils with high salt content.

The crops or plants used will need different soil conditions and endure different types of environmental and climate stresses.

It takes a lot of biochar You will need about 2 kg (4.4 lbs) of dry green yard waste to produce 0.5 kg (1.1 lbs) of biochar, depending on the type of waste used. If your garden is a about 5x5 meters (17x10 feet), then to add 1% biochar into the top 15 cm (6 inches) of soil, you will need about 55 kg (120 lbs) of biochar or about 50 kg (110 lbs) of biochar or about 200 kg (440 lbs) of dry green waste. This is the same as mixing approximately one part biochar to 100 parts soil by weight (1:100).

Recommendation 1: If the biochar is applied by itself, try using it in small plot areas at increasing amounts (1, 2, 4%...). More biochar may be applied to garden soils over time or when mixed with compost. Also, use biochar as backfill for outdoor plants mixing up to 5% (~1:20 parts of biochar to soil).

Recommendation 2: Higher biochar soil applications are possible using compost-biochar mixes. Follow normal compost application guidelines for Arizona.

Recommendation 3: Avoid applying biochar to garden soils that will be turned over regularly or stay dry for long periods. Plowing or rototilling dry soils amended with biochar may release biochar dust into the air. Caution! Do not use biochar or biochar-compost mixes as top mulches because small biochar particles (which are about 10 times lighter than soil particles) may become airborne in windy-dry weather.

5. Where Can I Get Biochar?

To date there are no large commercial facilities that produce biochar in the Southwest US. The US Biochar Initiative (USBI 2017) is an excellent source of information and also maintains a list of where to purchase biochar and biochar equipment. Additionally, biochar soil additives and soil blends are beginning to find their way into retail stores and online markets but are expensive. As with any commercial product to be added to the garden, be sure it is specifically sold for garden use. Biochar made for other purposes (such as biofuel) may contain unwanted contaminants. Also, follow the safety cautions mentioned in this document as even “low-dust” commercial biochars will still have some dust that is hazardous to inhale.

Summary

- The use of biochar as an amendment to improve soil goes back to thousands of years, as does its production for basic heating and cooking needs. Until recently the modern use of charcoal did not extend beyond barbeque cooking.
- Homeowners can now produce biochar with yard wastes using a variety of stoves and kilns either purchased or home-made following basic fire safety rules. Biochar is great for outdoor cooking and can improve the quality of garden soils.
- Biochar is a great way of using green waste that is good for the climate and environment.
- Adding biochar to soil will store carbon for many generations and help lower CO₂ gas emissions, a major cause of global warming.
- Semi-arid soils common in the Southwest are not ideally suited to benefit fully from biochar amendments since they have an alkaline pH and plenty of salts. Biochar commonly add salts and raises the pH of these soils short time.
- Adding biochar to semi-desert soils will make plant more drought resistant, reduce plant nutrient losses, and when mixed with compost will also improve soil structure.

Biochar materials should be handled and applied to soils prudently, (Table 1).

Table 1. Recommendations and Cautions for using biochar in home gardens.

Recommendations	CAUTIONS
Avoid mixing yard wastes when making biochar.	Biochar materials must be handled outdoors and stored in sealed bags to avoid dust exposure. Wear a dust mask or wet biochar before handling to reduce dust. Avoid disturbing garden soils when dry to limit dust exposure. Do not add biochar to top mulches.
Use biochar with average sizes ¼ inch or less.	
Soak biochar overnight (then drain) several times before use to remove the concentrated salts.	
Ratio of biochar to soils can range from 1:100 to 1:10 (if pre-mixed with compost) in the garden.	
Use biochar in soil backfills, in potting mixes or better yet, with compost mixes.	
Keep the biochar in the ground where it is not easily airborne.	

Glossary

Ash: The product of a wood fire after complete combustion. Ash may contain many trace minerals and elements including: carbonates, oxides, and hydroxides of calcium, potassium, magnesium, sodium, iron, copper, manganese, zinc, and phosphates and sulfates, and other trace elements.

Bulk Density: Average weight of a material divided by its volume. A typical agricultural soil is assumed to have a bulk density of 1.3 grams/cubic centimeter (g/cm³) (11 lbs/gallon), but this may vary by more than 30% depending on the soil composition and compaction.

Charcoal: Black material (also called black carbon) produced by the partial combustion of wood. It is composed mostly of carbon and smaller amounts of oxygen and hydrogen in addition to the trace elements and minerals also found in ash.

Fossil Carbon: Buried ancient plant and animal carbon deposited hundreds of millions of years ago now extracted and used as coal, petroleum and gas fuels.

Organic: Scientific term (used in this publication) – any carbon-based material or biomass from plant and animal tissue and wastes, and many types of synthetic chemicals such as plastics.

Pyrolysis: The chemical decomposition of organic material at elevated temperatures in the absence of oxygen. It should not be confused with Torrefaction.

Torrefaction: A mild form of pyrolysis at temperatures typically between 200 and 320 °C (~390-600 °F). Any organic material (such as green coffee beans for example) is placed in closed oven and roasted, not burned, using an external source of heat.

Wood: Plant-derived, organic material made mostly of carbon, oxygen and hydrogen, compose of sugar polymers (cellulose and hemicellulose), complex aromatic polymers (lignin), and smaller amounts of nitrogen, phosphorous, calcium and potassium and other trace elements also found in the ash.

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